

dielectric and so must be subcooled to prevent the formation of gas bubbles, which would result in undesirable partial discharges. Other vital components are the low-voltage and high-voltage bushings [67].

Superconducting transformers offer the following advantages:

- 1) Marked reduction in 50 Hz winding losses, resulting in higher efficiency
- 2) Enhanced magnetic flux due to low winding losses, permitting a reduction in the cross section of flux-guiding iron and thus a substantial decrease in the weight and hysteresis losses of the iron core
- 3) Short-circuit current limiting through the transition of superconducting windings to the resistive normally conducting state, resulting in simpler mechanical design of the windings (milder forces) and thus leading to higher current densities and lighter-weight windings

In recent years, a number of small single-phase model transformers rated at 100 kVA have been built by using submicron NbTi filament conductors and have demonstrated the advantages of superconducting technology.

The benefits of superconductivity become much greater if the helium-cooled windings of metallic superconductors are replaced by liquid-nitrogen-cooled HT-superconductor windings. The following values have been obtained in a paper study for a 1000 MVA power transformer with windings made of a multicore HT-superconductor wire with 5  $\mu\text{m}$  filaments (critical current density  $10^5 \text{ A/cm}^2$ ) in a matrix of Ag-Al alloy (conventional figures in parentheses for comparison):

Weight of iron core	91 t (280 t)
Weight of windings	5 t (58 t)
Iron losses	100 kW (300 kW)
"Copper" losses (converted to 300 K)	200 kW (2000 kW)

### 5.3.6. Superconducting Power-Transmission Cables

High-power superconducting cables are of interest for underground power transmission in and near densely populated areas. Because trans-

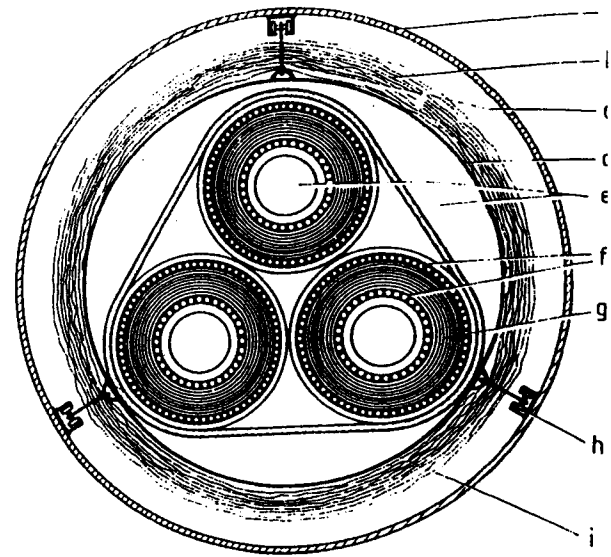


Figure 29. Liquid-nitrogen-cooled three-phase cable with high-temperature superconductors

a) Outer steel pipe; b) Superinsulation; c) Suspension; d) Nitrogen tube; e) Nitrogen coolant; f) Superconductors; g) Electrical wrapped-tape insulation; h) Suspension track; i) Vacuum

mission distances are relatively short (10–100 km), three-phase cable is preferred. Figure 29 is a schematic of such a cable with HT-superconductor cores and liquid-nitrogen cooling. The flexible, hollow cable cores are of coaxial design. The actual phase conductors, made of superconductors (wires, tapes) in helical form, are enclosed in electrical insulation (wound tapes of polypropylene or polyethylene) and surrounded by a return conductor in which the a.c. current flows in the opposite direction to the phase conductors. As a result, no a.c. electromagnetic fields are produced outside the cores. A rigid or flexible double-walled thermal insulation layer surrounds the flexible cable cores; liquid coolant flows through the inner tube, while the outer one is at ambient temperature.

The practicability of superconducting cables has already been demonstrated in a number of experimental cables with helium-cooled metallic superconductors. The largest project was a two-phase model cable of 115 m length with a power capacity of 1000 MVA at a voltage rating of 138 kV [68]. However, cables with helium cooling become economically competitive with conventional water-cooled oil cables only when carrying ca. 4000 MVA and up. Estimates indicate that the economic breakeven point for nitrogen-cooled HT-superconductor cables may be as low as 1000 MVA.